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SOME INSTANCES OF MODERATE GLACIAL EROSION[1]

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Instances of marked glacial erosion have in recent years been reported from many sections, but very little has been written regarding evidences of moderate glacial erosion. In several widely separated localities I have found definite proof of moderate ice-erosion, which, in view of the growing tendency to assign to ice great erosive power, seems worthy of statement at the present time. These instances will be considered one by one.

SOUTHERN CENTRAL NEW YORK

South of the Finger Lakes is a plateau upland which was completely overridden by ice of the Wisconsin stage. Across this upland extends a series of moraines marking a prolonged halt of the receding ice. South of the recessional morainic belt there are numerous evidences of moderate glacial erosion, and no proof that the topography was perceptibly modified by ice-erosion, although during the time that the ice-front stood at the terminal moraine, about 50 miles farther south in Pennsylvania, the highest hills were completely covered.

The most important evidence of moderate glacial erosion in this plateau region is supplied by the presence, in numerous localities, of residually decayed materials in place, not only on lee slopes, but on hilltops and on the stoss sides of hills. The decayed material varies from discolored and disintegrated shale fragments beneath sandstone caps to fine-grained residual clay resulting from the decay of the shale (Fig. 1). In such cases the sandstone cap layers are cracked and broken, and the decayed shale is in some instances three feet below the surface. That this clay is not the result of postglacial decay is proved by the fact that in some places the striæ on the sandstone caps are not yet destroyed by weathering.

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[1] This paper was presented before the first meeting of the Association of American Geographers at Philadelphia. The facts relating to New York were discovered while working for the U. S. Geological Survey, and are published by permission of the director.

It is only occasionally that cuts fresh enough to reveal the actual condition are found, but it is evident in the field that unremoved products of rock decay are widespread. This is proved by the presence in the fields of abundant slabs of sandstone, many of which are profoundly decayed, with a deep rim of oxidized rock, and with fossils completely weathered out. Very often plowing has encountered weathered sandstone caps under the thin upland soil, and, by upturning the slabs, has transformed the fields to such stony areas that the sandstone fragments cover fully 50 per cent. of the area. The till of this region is made up largely of local sandstone fragments, mixed with residually decayed clay and a relatively small proportion of foreign stones and rock flour, making a very peculiar soil. The

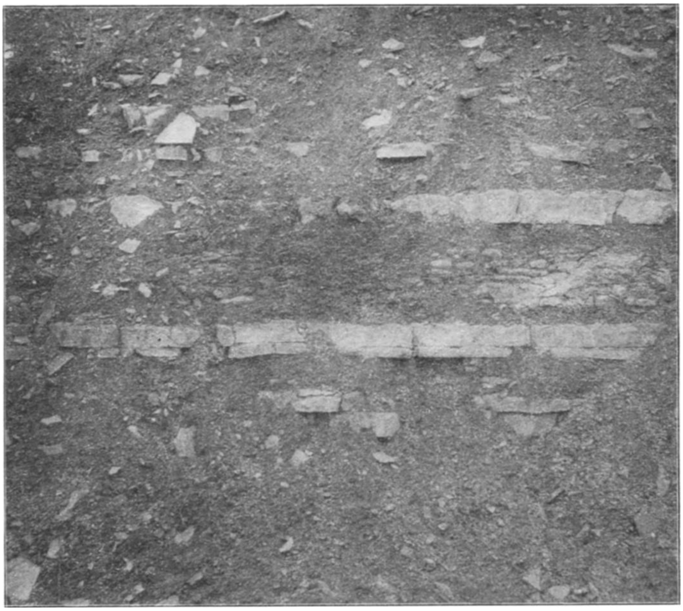

FIG. 1.—Decayed shale between sandstone layers, one mile east of Berkshire, N. Y., on Harford (U. S. Geological Survey) Topographic Sheet. The shale shows spheroidal weathering and between the nodules is residual clay.

Soils Bureau of the U. S. Agricultural Department recognized this peculiarity, and in mapping the soils of the Elmira Sheet correlated the upland till with a type of residual soil under the name of Hagerstown shale loam.

This residually decayed material is not confined to a small area, but has been found in the mapping of glacial deposits on eight topographic sheets, and it is certain that throughout this area there has been such slight glacial erosion that in many places, even where conditions seem favorable, the residually decayed products were not removed by the Wisconsin ice-sheet. Whether this is preglacial or interglacial decay is not certain; but so far no facts have been discovered in this region to prove an earlier ice-advance.

It is true that this is a region in which the length of ice-occupation was relatively brief, and in which the hilly topography was opposed to vigorous ice-action. But even under these conditions it is a significant fact that ice could have moved over it and have advanced 50 miles beyond it, building a traceable terminal moraine, and yet leave so much decayed rock even in exposed places, like hilltops and stoss slopes.

THE CAYUGA VALLEY

At Portland quarry, about 6 miles north of Ithaca on the east side of Cayuga Lake, the excavations for the removal of the Tully limestone have revealed a condition of profound decay. By this decay the upper layer of limestone has been separated into rounded blocks, with a reddish residual clay occupying the spaces between them, both along the vertical joint planes and along the nearly horizontal stratification plane between the two upper layers. The decay extends from 2 to 3 feet below the surface, and the residual clay is several inches thick. Delicate glacial striæ are still perfectly preserved on the surface of limestone blocks between and beneath which this residual clay occurs.

The depth and extent of this decay, together with the evidence of slight postglacial decay furnished by the glacial striæ, demonstrate that this residual clay was formed before the advance of the Wisconsin ice-sheet, and that in this place the erosion by the last ice-sheet was insufficient to remove the products of earlier decay. The site of this quarry, near the junction of Salmon Creek and Cayuga Lake on a nearly level bench below the edge of the steepened slope of Cayuga valley, is a point where, if anywhere in the valley, glacial erosion should have been extensive.

Farther north, between Union Springs and Cayuga, marked decay was revealed in the gypsum beds of one of the quarries; but this has now been removed. It was situated on a level surface near the northern end of the Cayuga trough, at a point where glacial erosion should have been pronounced, and in a soft stratum which ice-erosion would easily wear away.

At frequent points near the heads of Cayuga and Seneca valleys, notably near Ithaca and Watkins below the edge of the steepened slope, there are pronounced cliffs, often several score yards in length and from 5 to 15 feet in height, with sharp edges and angles whose formation by ice-erosion is inconceivable. Their length and height, as well as the absence of rounded edges, indicate origin by weathering and not by ice-erosion; and that they were not produced after the ice disappeared is proved in a number of cases by the presence of till and moraine banked up against them and partly burying them.

A system of hanging valleys tributary to both the Cayuga and Seneca troughs ends at about the 900-foot contour, below which the valley slope is decidedly steepened. Down this steepened slope extend old gorges antedating the last ice-advance, and partly buried beneath deposits of the Wisconsin stage. So far as can be seen, the gorge walls are not markedly worn by ice-erosion. It has been proposed as a theory that the steepened slope and great depth of the Cayuga and Seneca valleys are the result of glacial erosion; but that such profound erosion, amounting to at least 845 feet in the Cayuga and 1,500 feet in the Seneca valley, could have been performed without erasing these earlier gorges, or at least so modifying them as to give evidence of such erosion, seems inconceivable.

The evidence in the Cayuga valley is believed to demonstrate that the work of erosion by the Wisconsin ice-sheet above present lake-level was very slight. What occurred below lake-level or during possible earlier ice-advances is not clear; but if this evidence eliminates erosion in the visible part of the valley by the only known ice-advance in this region, as it seems to do, it throws doubt upon the whole hypothesis of ice-erosion for this valley, notwithstanding the remarkably straight, smooth sides, the steepened slope, and the hanging valleys whose characteristics suggest ice-erosion origin.

CAPE ANN, MASSACHUSETTS

This cape, extending into the sea north of Boston, has upon it an interesting morainic deposit in which there are large numbers of bowlders (Fig. 2), in some cases with bands of bowlders piled one on the other, making bear-den moraines (Fig. 6). It is no overestimate to state that there are tens of thousands of bowlders on the Cape, and that fully 90 per cent. of these are of local origin, especially granite of which the Cape is chiefly made. So far no satisfactory explanation of this marked accumulation of local bowlders has been proposed.

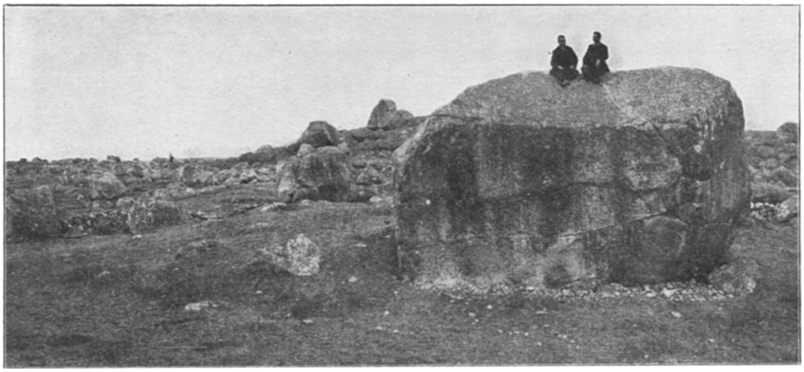

FIG. 2.— Bowlders in the Cape Ann (Mass.) moraine, showing the ordinary condition of the moraine surface.

Years ago I did work on the geology of Cape Ann as an assistant to Professor Shaler, and the result of his studies was published by the U. S. Geological Survey.[1] Numerous visits since then, together with the fact that quarrying operations have opened up scores of new exposures, have furnished new facts which show conclusively that ice-erosion on Cape Ann was very ineffective, and that the large numbers of bowlders are probably directly due to this fact. Indeed, they evidently represent the slightly moved bowlders of decay prepared for removal before the last ice-advance. The evidence of moderate ice-erosion is of several kinds, as follows.

[1] *Ninth Annual Report*, U. S. Geological Survey (1887-88), pp. 529-611.

Larger valleys.—In the first place, the major valleys all antedate the ice-advance, for they extend at all angles to the direction of ice-motion, and have all the characteristics of subaërially formed valleys.

Angular cliffs.—A second evidence is furnished by angular cliffs, especially on lee slopes. These vary in elevation from an inch or two to a score of feet or more, being due either to the influence of joints or of dikes. They are seen in all parts of the Cape, the smaller instances being revealed where quarrying operations have recently stripped rock-surfaces bare.

Some of the smaller cliffs may be the result of plucking, but the larger ones are certainly not of this origin. The smaller cliffs are often associated with incompletely developed *roches moutonnées* surfaces, which conform closely in outline to the concentric joints of the granite (Fig. 3). Viewed from the stoss side, these surfaces are typical *roches moutonnées*, but from the lee side they appear angular, with small cliffs extending from one *roches moutonnées* down to the next lower joint plane.

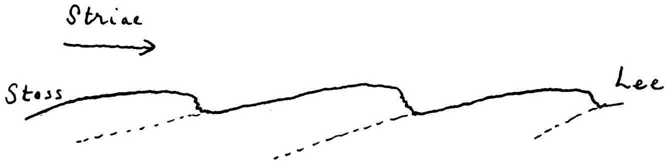

FIG. 3.—To show the relation of *roches moutonnées* surfaces and minor cliffs to the concentric jointing (dotted lines) of the Cape Ann granite.

Dikes.—In a number of places there are small valleys where dikes cross the granite, and these occur at all elevations, even above the level at which the sea formerly stood. They extend at all angles to the direction of ice-motion, and, being occupied by drift, are not of postglacial origin. Every evidence proves these valleys to be due to greater decay of the dike than of the inclosing granite; and that the ice should not have eroded the granite down to the level of this dike decay is proof of its slight erosive power at this point.

At the Rockport granite quarry one of these decayed dike valleys extends up to the edge of the quarry, and, while the residually decayed surface material is gone, there is evidence of some decay in the dike even to the bottom of the quarry. This decay consists of the development of abundant joints in the dike and a slight disintegration along them. A similar case occurs where a large porphyritic diabase dike crosses a quarry at Pigeon Cove; but here residual clay remains along the joints, by which the dike is separated into a series of rounded bowlders.

"Sap."—In all the quarries at Cape Ann the granite is stained yellow along both the vertical and horizontal joint planes. This stain, which in some cases extends three inches into the granite, is known by the quarrymen as "sap." It is due to a partial disintegration of the iron-bearing minerals and consequent staining of the granite. The depth to which this stain extends in the quarries, being found even at the very bottom of the largest, and the extent to which it enters the rock, are altogether too great for postglacial decay.

Joint planes.—Almost uniformly over the Cape it is the case that joint planes are much more numerous in the upper than in the lower portions of the quarries.[1] They are in some places so close together that small quarries have been opened and, after being worked for a while, have been abandoned because the "grout" (small irregular blocks stained with "sap" and useless even for making paving blocks), which must be handled and disposed of, is too abundant. These joint planes have evidently been developed by weathering, and by weathering of longer duration than postglacial times would permit. Glacial erosion has not been sufficient to remove this upper zone of jointed granite, although the joints produce masses favorable for plucking.

Interglacial (?) beds.[2]—At Stage Fort, just outside of Gloucester, there is a bed of fossil-bearing sands, clays, and gravels, overlain by till and grooved by glacial erosion. The layers are crumpled by the ice-shove. Although in the lee of a range of hills, it would hardly be expected that such a deposit would escape vigorous erosion.

Decayed granite.—In Lanesville, on the stoss slope of the Cape, and in a situation where there is no topographic reason for protection, there occurs in the Edwin Canney quarry a striking instance of decay in the granite (Figs. 4 and 5).[3] This decay, which extends along both the vertical and horizontal joint planes, has produced a gravel of disintegration to a depth of five feet and with a width, in one or two places, of eighteen inches. By it the granite has been separated into rounded, bowlder-like blocks incased in disintegrated granite gravel exactly like those revealed in quarries in Maryland where the granite is covered by a residual soil.

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[1] See Plates LXVI and LXVII in *Ninth Annual Report*, U. S. Geological Survey, 1887–88.

[2] Tarr, *Bulletin of the Museum of Comparative Zoölogy*, Vol. XLII (1903), p. 189.

[3] See also Plate LI, *Ninth Annual Report*, U. S. Geological Survey, 1887–88.

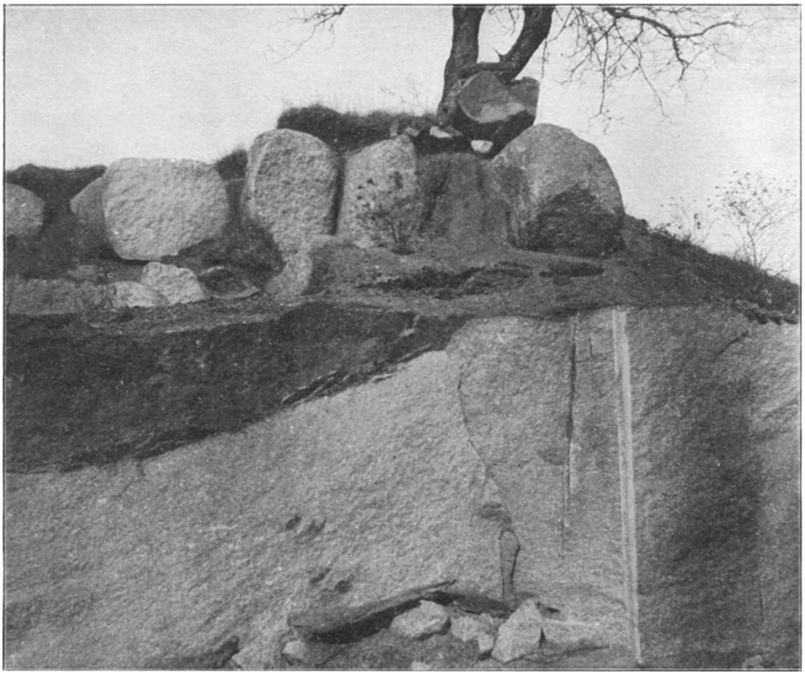

FIG. 4.—Disintegration of granite along joint planes at Lanesville, Cape Ann, Mass. Gravel underlies these bowlders, which are in place.

Nowhere on the Cape is so good an instance of decay found as this; but in dozens of places decayed gravel occurs along the joint planes, in one or two instances to a depth of five feet. These localities are found in all parts of the Cape, and on both stoss and lee slopes. In a number of places granite masses that are thus partly incased in gravel are scratched and polished on the surface, showing how slight has been postglacial decay, and proving that the disintegration farther down cannot be postglacial.

That these masses should have resisted ice-erosion is remarkable; and that this erosion has not extended below the level of the disintegrated granite is clear proof of its general weakness on Cape Ann.

The till.—One of the most striking features of the till of Cape Ann, aside from its bowldery nature, is its sandy and gravelly condition. In some cuts the till very closely resembles the disintegrated gravel above described, and everywhere it seems to contain a large percentage of this decayed material. From the field evidence I am convinced that the till of Cape Ann is in large part made up of gravel disintegrated before the last ice-advance and pushed forward a short distance to its present position.

The bowlders and bear-den moraines.—It has been stated above that the bowlders of Cape Ann are prevailingly local, probably as much as 90 per cent. being of rocks at present in place on the Cape. Many of these are angular (Fig. 2), with joint-plane faces, as if broken from a ledge and carried a short distance without attrition. On the other hand, many, although carried only a short distance, are well rounded.

Both of these conditions are readily explained on the theory that they represent the dislodged products of decay prior to the ice-advance. Fragments surrounded by disintegrated gravel were rounded; those broken from the markedly jointed sections had angular faces. No other explanation that has occurred to me will account for this vast number of local bowlders; and the fact that some unremoved masses are left (Fig. 4) points clearly to this explanation as the true one.

The bear-den moraines (Fig. 6), representing bands of excessive bowlder accumulations, occur at various levels, so that they can scarcely be assigned to marine action, on the assumption that when they were accumulated the sea stood at the ice-front. Opposed to this theory also is the further fact that some of the occurrences are on protected valley slopes where sea-action could not have been very effective. So far as observed, they are all situated on lee slopes, which suggests that they were combed over the edges of the hills by ice-push, and perhaps added to accumulations which, being in the lee, the ice was incapable of removing. The only alternative explanation that appears is that they owe their origin to the action of water run-

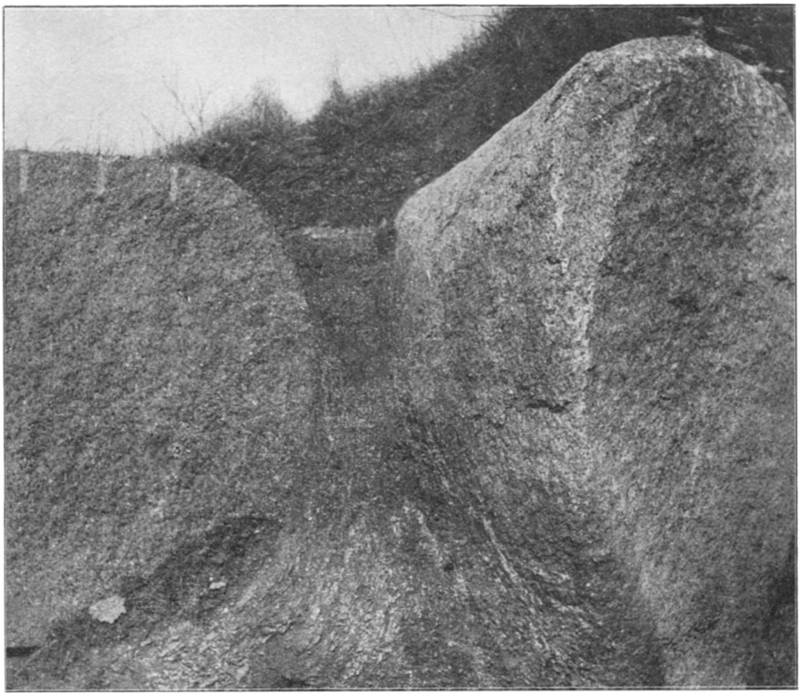

FIG. 5.— Disintegrated granite along joint plane at Lanesville, Cape Ann, Mass., showing a portion of Fig. 4.

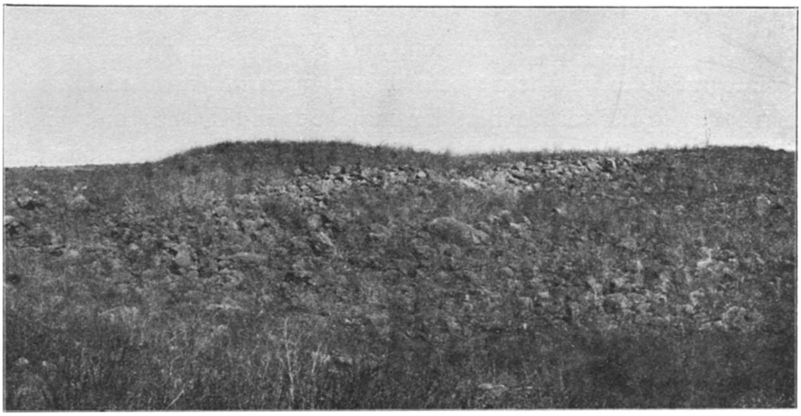

FIG. 6.— Bear-den moraine, on lee (southeast) slope of a granite hill, Cape Ann, Mass.

ning out from the ice-front, and, by removing the smaller fragments, concentrating the larger ones. Between these two theories I have been unable to find facts to decide.

Decayed bowlders.—Many of the bowlders have been broken open along joint planes since they were deposited by the ice. Although this is the result of postglacial weathering, it is due to the presence of joints partly developed before removal from the ledge. Other bowlders have disintegrated to gravel hills (Fig. 7) since they were brought to their present position, and every gradation from slight disintegration to instances where only a mass of gravel remains to mark the site of a former bowlder, may be found by the score. This disintegration is surely postglacial; but, taken in connection with other facts indicating preglacial decay, it seems certain that such decay must have been made possible by the fact that, before removal from the parent ledge, the rock was already weakened by decay. Nowhere on the Cape is there such difference in the granite in place as to permit marked decay on one surface and slight decay on another, as is true among the bowlders. On the contrary, wherever the thin till-cover has been stripped from the bed-rock, its surface is found to be polished or scratched, proving that postglacial weathering has done little work.

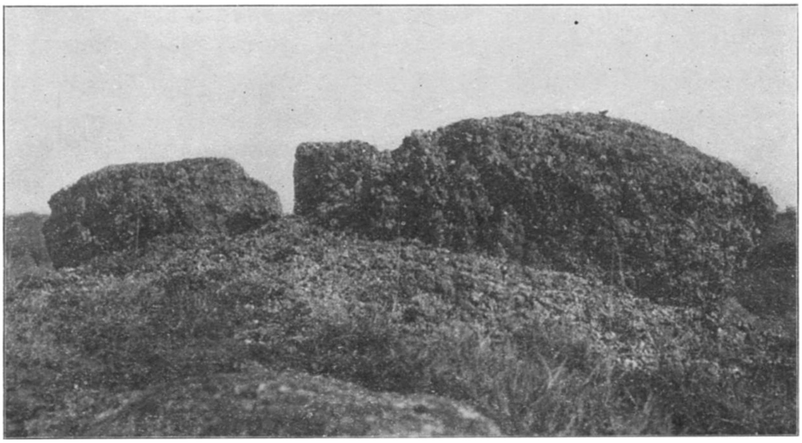

FIG. 7.—A granite bowlder in process of disintegration on Cape Ann, Mass. Other bowlders are represented only by heaps of gravel.

Conclusion.—That glacial erosion failed to remove the products of preglacial decay on Cape Ann is evident from the facts stated above; and that the marked accumulation of bowlders on the Cape is due to this lack of erosive power is advanced as a theory toward which all facts point, while no facts at present known oppose it. Whether there are reasons why the ice was locally thus ineffective, or whether it is a common condition along the New England coast, I cannot say. The Cape is a moderate salient against which ice-currents may have divided, leaving this region only slightly affected by its erosive action. Facts from a wider area must be obtained to settle the question whether this condition is local or general along the New England coast.

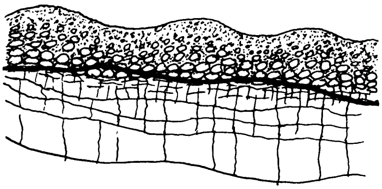

FIG. 8.—To illustrate the probable changes at Cape Ann. A jointed granite with joint planes increasing in number toward the surface, changing to a condition of bowlders with gravel between, and capped by residual soil, has, by ice erosion, been lowered to the level of the heavy line.

TURNAVIK ISLAND, LABRADOR

This island, which is approximately in latitude 55° N., is one of a number of islands in an indentation on the Labrador coast. It rises from 300 to 400 feet above the water and is a barren mass of rock, mainly porphyritic gneiss, so far as examined. Its surface is strongly glaciated, with numerous very perfect *roches moutonnées* forms, and many perfectly preserved striæ and deep grooves, but with very little till and few foreign bowlders.

Crossing the gneiss are a number of diabase dikes, one of which is 60 feet wide, and where these dikes occur their sites are quite uniformly indicated by chasms. The large 60-foot dike, whose site is marked by a long, deep valley (Fig. 9), extends at right angles to the direction of ice-motion, so that the valley cannot be explained by ice-erosion. That the chasm has not been formed since the ice left is proved by its rounded, ice-worn edges, and by the presence of fresh striæ on its walls. The valley is evidently the result of earlier decay; but that the ice removed the entirely disintegrated products of this decay is proved by the fact that fresh diabase was collected in the bottom of the valley.

This dike chasm, produced before the last ice advance, was not entirely erased by glacial erosion, proving that at this point the ice did not accomplish much work. It would be interesting to know how widespread this weakness of ice-erosion was along the Labrador coast, and whether this particular instance is due to some local retardation of the ice; but facts are not available for answer of these questions.

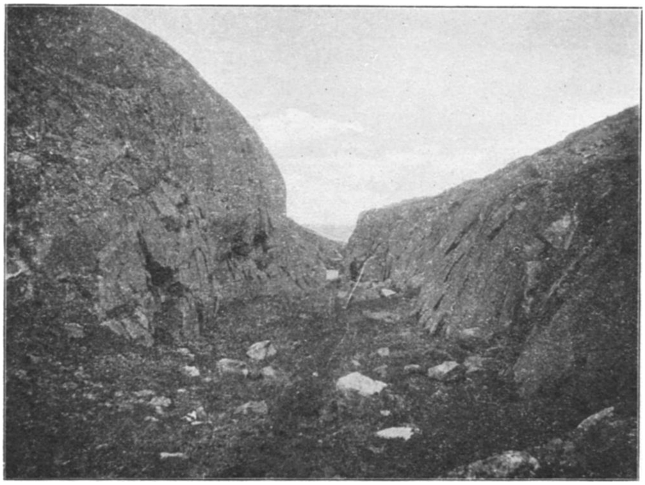

FIG. 9.—Dike valley, formed before last ice advance, on Turnavik Island, Labrador.

These observations, in widely scattered localities, do not prove anything beyond the regions in question. It is a well-known fact that the erosive power of ice varies with the conditions, and it is possible that close by some of these localities of moderate ice-erosion there may have been profound changes caused by the ice. Nevertheless, such pronounced cases of moderate ice-erosion, in such widely different situations, including surroundings apparently favorable to erosion, prove that under some conditions the erosive power of the continental glacier was very limited. More facts are necessary before the exact efficiency of the ice as a sculpturing agent can be determined, or the reasons why it erodes little in one place and apparently a great deal in another. All that is claimed for this paper is that it is a small contribution toward the accumulation of facts necessary for these determinations.